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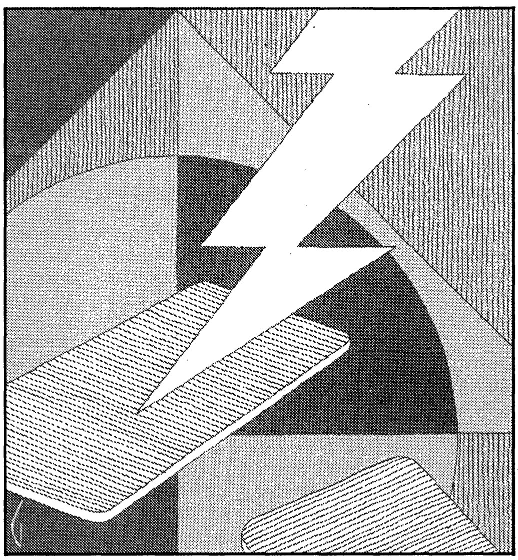
Store Data in a Flash

Flash-memory ICs offer new options for personal computer storage

Walter Lahti and Dean McCarron

Normally, you'd think of a flash flood as a natural disaster, something that could pick you up and carry you away. But the flood of flash memory that is about to reach the personal computer world will be a positive event. It will carry the power to expand the reaches of personal computing.



Flash memory is a nonvolatile memory IC. Born of the blending of EPROM and EEPROM, the flash IC is functionally and technologically the offspring of these parents (see the text box "Do You Remember?" on page 312). It is reportedly named for the speed with which it can be reprogrammed.

While flash and EPROM memory cells usually contain a single transistor, a DRAM cell typically contains a transistor and a capacitor, an EEPROM cell two transistors, and a static RAM (SRAM) cell four or six transistors. Obviously, the more cells, the more real estate (silicon) a memory requires. And real estate is always expensive.

Advantages of Flash

Flash's two significant attributes, nonvolatility and DRAM-like speed, are ideal for solid-state "disk" drives. Flash-based disks are very fast compared to most available disk drives (see figure 1). In 120 nanoseconds, you can access data stored in flash memory, while it takes 15 to 30 milliseconds to access data stored on today's typical hard disk. In some implementations, such as in portable computers, the speed advantage of flash over disk drives is even greater.

Today, a personal computer's hard disk drive is one of its most power-hungry components. When you use a desktop machine, you may not notice this power consumption. But the power a battery-operated portable can supply is limited—and hard disk drives use up that power quickly. Most portables today require fairly sophisticated power management facilities to extend the amount of time the machine can be used.

A portable's power management facility often turns off the hard disk drive if it isn't being used. While this is great for extending a portable's limited battery life, it is terrible for performance. When the power comes back on, the disk drive's motor can take several seconds to bring it up to speed before disk I/O can begin. A flash-based disk needs no warm-up. When you turn on the power, the data is immediately available. With no waiting, you experience no loss in performance.

In addition to achieving power savings from an "instant-on" flash disk, you also realize savings from not having to operate power-hungry motors and servos. A 1-megabyte flash disk requires a maximum of only 1.2 watts while operating.

ILLUSTRATION: JOE GAST © 1990

Do You Remember?

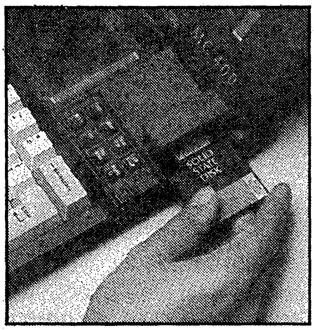
There are two kinds of memory: volatile and nonvolatile. Memory such as DRAM is called volatile if it forgets what it had stored when you turn off your computer's power. Memory such as ROM is called nonvolatile if it retains its data whether or not your computer's power is on. As all users who have ever turned off their computers before saving files to disk can tell you, the DRAM used in your personal computer to store programs and data cannot retain information without power.

DRAM, however, is reprogrammable; the information it contains can be changed. When you load a new file, the new information replaces the old. ROM, though, is not reprogrammable—the programs and data in ROM are permanent, and you can't change them.

In the early 1970s, the only semiconductor memory available was DRAM, its cousin static RAM—which is also volatile—and ROM. The choices open to computer designers were using memory that was reprogrammable but lost information without power, and using memory that always retained information but could never be changed. What designers really needed was memory that could be reprogrammed in the system and that also retained its contents when the power was off.

A few years after DRAM became available, a new kind of memory known as electrically programmable read-only memory, or EPROM, was introduced. EPROM is reprogrammable and nonvolatile. But it has one drawback. In order to reprogram EPROM chips, you have to remove them, expose them to high-intensity ultraviolet light for as long as 20 minutes, reprogram them, and then replace them in your computer. Thus, EPROM fell short of being the ideal memory. Today, because vendors find them easier to program, EPROM chips are largely used as replacements for your personal computer's ROM.

Electrically erasable programmable read-only memory, or EEPROM, was introduced in the late 1970s. EEPROM



Psion uses four Intel 1-Mb flash-memory ICs in its credit-card-size solid-state disk.

(like EPROM) is reprogrammable and nonvolatile, and it can also be easily reprogrammed within the computer.

Still, there are drawbacks. EEPROM is slow and expensive and doesn't hold very much data. Today, you can store 1 megabit of data in an ordinary DRAM chip. You can access the data in 80 nanoseconds, and it costs $5. In contrast, it takes 150 ns to access a 1-Mb EEPROM, which costs $265.

In the mid-1980s, Toshiba Semiconductor invented flash memory. About the same time, Intel and Seeq Semiconductor were also working on flash memory. While each manufacturer built its flash memory differently, they operate similarly.

Like both EPROMs and EEPROMs, flash memory is nonvolatile and reprogrammable. But it has none of the faults of these other types of memory. Unlike EEPROM, it is inexpensive: Today, a 1-Mb flash memory costs about $15. Unlike EPROM, flash memory can be reprogrammed electrically while it is embedded in the system—either by you or via system software.

Still, one drawback remains. With DRAM, you can change a single bit at a time, but with flash memory, you can change only a sector (consisting of multiple bytes) at a time. While constraints of sector-level reprogrammability prevent it from replacing your computer's DRAM, flash memory is well suited to other applications.

The type of storage that hard and floppy disk drives provide resembles that of flash memory. Disks are nonvolatile—they hold onto data with or without power. And disks are reprogrammable—you can change the files whenever you want to. The similarities between flash memory and disk storage led to the building of "disks" based on the concept of flash memory.

A flash disk isn't a disk drive at all; there are no disks or moving parts. A flash disk is a set of flash-memory parts mounted in a credit-card-size package that acts as a hard disk. This same set of parts could be mounted on a board inside a machine. The difference between the two is that one is removable storage and one is fixed storage. A flash disk emulates a disk drive.

A flash disk is built from one or more flash-memory ICs and some controlling logic devices. For example, to build a 512K-byte flash disk, you could connect four 1-Mb flash-memory ICs and place them on a small card. Psion has used this principle with its flash disk (see the photo).

Flash disks operate fairly simply. At the hardware level, the computer simply sends digital read or write signals to the disk with the address of the information. If it is a read signal, the disk responds with the requested information. If it is a write signal, the disk takes information from the computer and stores it.

In addition to flash-disk hardware, you also need software to manage the files on a flash disk. This file-system software handles creating and deleting files, changing the file sizes, and formatting the flash disk. Microsoft has worked with Intel to create the Microsoft flash file system, a standard MS-DOS-compatible flash-disk interface that makes it much easier for vendors to use flash disks in their computers.

The lowest-power hard disk drives today require about 3 W.

The fact that flash-based disks have no moving parts carries with it yet another advantage—reliability. While hard disk drives have become remarkably tough, on occasion they still do crash.

Flash-based storage is very reliable because a flash disk is as tough as the rest of the electronic hardware in a personal computer. It takes a lot for a flash disk to fail: The flash memory must be damaged physically, through destruction of the device package, or electrically, by an extreme electric shock or a power spike.

Disadvantages of Flash

Flash memory's extremely high speed, low power, and high reliability would seem to make it the ideal storage technology. Unfortunately, there are two significant drawbacks to flash disks. The most severe limitation is its cost. A conventional 40-MB hard disk drive costs about $320, or $8 per megabyte. Today, a 1-megabit flash IC costs $15. Eight flash ICs are needed per megabyte of flash disk, making a flash disk cost about $120 per megabyte.

Thus, you would have to pay about $4800 for a 40-MB flash disk, or about 15 times what an ordinary hard disk drive would cost. Because of this present inequality, the first mass-produced flash-based disks probably will store less than 40 MB. In the future, flash-based disk prices will certainly decline, making large amounts of flash-disk storage more affordable. In a few years, you should only have to pay about $600 for a 40-MB flash disk.

The other problem with flash disks is that they can't compare with hard disks in density. The highest-density flash memory available today stores 2 Mb per IC—you would need 160 of these ICs to produce a 40-MB disk. Like all memories, flash memory is expected to grow in density, so eventually far fewer ICs will be needed.

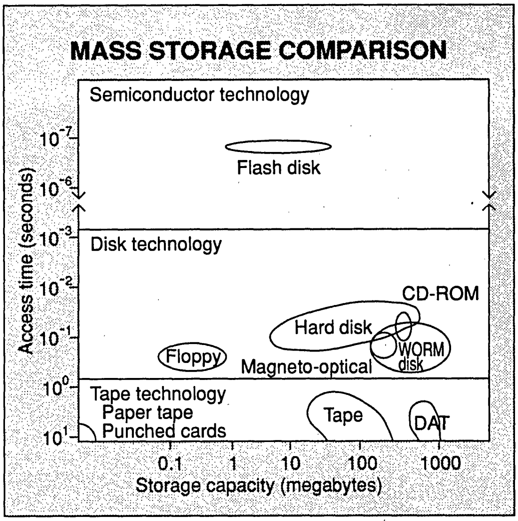
Two Flavors

Manufacturers currently offer flash devices in two programming flavors: those that require a 5-volt power supply, and those that require a 12-V supply. With both erasure and programmability possible at 5 V, only one power supply is required at the system level. The benefits of this feature are reduced system-component cost and space savings. Thus, flash is ideal for portable-computing applications.

The 5-V flash cell is generally a modified two-transistor (or split-gate) derivative of EEPROM and is packaged with a different pin-out than the 12-V varieties. Five-volt programming lets a system interface with the device in much the same way it would with SRAM. Therefore, for some applications, a flash device can replace SRAM, particularly in systems that use SRAM with battery backup.

While both 12-V and 5-V flash memory can be used as an SRAM replacement, the 5-V feature becomes more desirable for portable equipment where no external 12-V power is available and the addition of a 12-V power supply is not feasible.

Figure 1: *Flash disks are 125,000 to 250,000 times faster than today's hard disk drives. However, they are limited to up to 40 MB in capacity, whereas hard disk drives can store from 5 MB to 1 gigabyte.*



Ideal for Laptops and Palmtops

Laptop and notebook computers are the ideal applications for flash disks. With current hard disk drives, you must carry around heavy batteries, deal with short amounts of work time, or suffer from hard disk drives operating at floppy disk drive speeds. Flash disks will answer all your critical needs for laptop and notebook computers by providing speed, rugged construction, and low power consumption.

You can also benefit from flash memory in other implementations. Flash will let you update your laptop's ROM with the latest versions of DOS, or any other operating system, whenever you want to. Laptops save space on disks and in RAM by placing the operating system in ROM. The problem with this is that you can't update the operating system without replacing the entire ROM—an expensive proposition. Thus, laptops often use old but reliable versions of DOS. Using an old version of DOS may mean that your computer won't need a ROM replacement in the near future, but it may not run recently written programs, either.

One thing lacking in palmtop computers, such as the Poqet PC and Atari Portfolio, is small, convenient mass storage. Without any optional peripherals, their storage is limited to programs on ROM cards and memory-expansion cards that lose their contents when they are removed. With flash-based memory cards, you can put your own programs and data onto the card, modify them at will, and not worry about losing the information when you remove the card. These features make flash-memory cards the logical choice for the palmtop's missing "floppy disk drive."

Laser Printers

If you use a laser printer, you can benefit significantly by using flash memory instead of ROM. In laser printers, ROM stores programs and fonts. ROM replacements are expensive because printer-control language programs have become large and are subject to frequent upgrades and improvements. Using a laser printer equipped with flash memory instead of ROM to store control-language programs, you can reprogram your printer's control language yourself at no cost and without replacing any ROM.

Currently, laser-printer font-storage options leave much to be desired. You have three choices. You can download a font to the printer each time it is needed, wasting your time and the laser printer's memory. You can place a font in a ROM cartridge and plug it into the printer, but you are limited to a selection of only a few fonts out of the hundreds available. Or you can store a font on a dedicated hard disk connected to the printer.

But when you use flash memory inside your printer, you only have to download a font once and it remains in your printer until you choose to delete it from the printer's memory. Because you decide which fonts are stored in the printer's memory, you can really personalize them according to your preferences. You no longer have to buy cartridges that come with a half-dozen fonts just to get the one font you need.

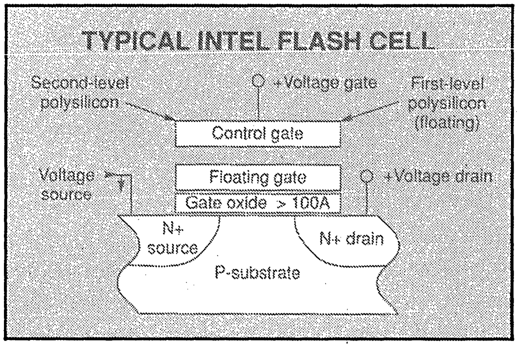
Fabrication Techniques

Flash devices are manufactured using designs and processes similar to those used for EPROM and EEPROM, so the technology is evolutionary rather than revolutionary. Because manufacturers have dealt with similar products, they will be able to climb the learning curve much more rapidly than if the technology were completely new. Thus, vendors planning to produce flash memory should be able to attain manufacturing costs close to, but perhaps not equal to, those enjoyed by EPROM.

However, flash devices are a bit more complex and more silicon-hungry than EPROM devices. The most common flash chip is an array of single-transistor memory cells and looks much like an EPROM (see figure 2). It is slightly larger than an EPROM of equal density to allow for the command port and peripheral circuitry that supports the in-system rewrite function and provides an on-chip processor interface.

The typical EEPROM chip is made of an array of two-transistor cells to enable bit-level erase/reprogram. For any given density, it requires much more silicon than either the EPROM or flash cell. Because a major cost determinant in any IC is the silicon required, the EEPROM is a more expensive part.

Figure 2: *A flash-memory cell is basically one memory bit (on or off). An array of up to 4 million flash-memory cells can be connected to form a flash IC.*



Erasing and Reprogramming

In terms of reprogrammability, the flash IC falls somewhere between the traditional EPROM and EEPROM (see figure 3). A major difference between flash memory and EPROM is that flash does not require ultraviolet light for erasure, as does the traditional EPROM. While flash resides in your system, you can electrically erase it in much the same way as you would an EEPROM.

The energy needed to discharge or erase the gate in a typical EPROM is derived from UV light, a requirement that makes it difficult and time-consuming to erase an EPROM. In a typical flash IC or EEPROM, energy resident in the system can be used to erase a group of memory cells or the entire chip. This feature makes it easy and fast to erase a flash IC in the system.

You generally cannot erase a flash IC on a byte-level basis as you can with the EEPROM, but some flash ICs can be erased on a sector-level basis. Flash ICs are usually reprogrammable by hot electron injection, a solid-state physics process that uses the energy in the system. It is possible to program on a byte level, but because it is not possible to erase on a byte basis, reprogramming is limited to sector or the entire chip.

Because the flash device does not require UV light for erasure, the chip does not need to be housed in an expensive ceramic window package such as that required for an EPROM. Therefore, flash is also an excellent candidate for surface-mount technology.

The advantage of surface mount is that there is less distance between the device and the board. This reduction can lead to improved reliability, better system performance, and higher board density, as well as reduced cost. Also, the flash device can readily be packaged in memory-card configuration and handled as if it were a floppy disk, which is important to the portable computer world.

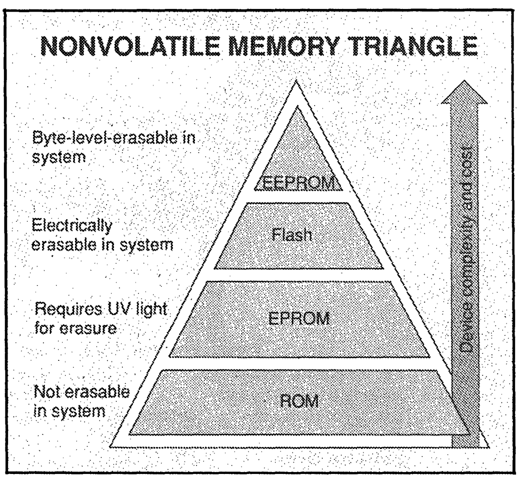
The total cost of using flash memory can be considerably lower than that for EEPROM and, with some applications, close to that for EPROM—about $6.50 for a 1-Mb EPROM versus over $250 for a similar-size EEPROM. On a comparable device-density basis, flash memory's $15 average selling price is much lower than the EEPROM's and greater than the EPROM's. With flash, application solutions are possible that would be impractical with either the UV-light erasure EPROM or the pricey EEPROM.

The law of the semiconductor jungle is that over time, all device types see improved performance and reach greater density levels. At the same time that silicon real estate is minimized, costs are significantly reduced. By 1994, the cost of a megabyte of flash memory is expected to move from its current level of about $120 to about $15.

Flash in the Pan?

Unless developers are able to overcome the current limitations of flash disks, you will probably continue to use hard disk drives on your desktop computer for mass storage. Hard disk drives are inexpensive and fairly reliable, and they can

Figure 3: *Technology trade-offs for semiconductor nonvolatile memories. As programming flexibility increases, so do device complexity and cost.*



Laptop and notebook computers are the ideal applications for flash disks.

store plenty of data. Although single-user personal computers will probably continue to include hard disk drives, eventually network servers will probably offer both hard disk drives and flash disks on-board.

On many servers, you frequently access files, such as programs, that are rarely changed. Flash disks are ideally suited to perform this service. You can store seldom-changed program files on flash disks, relieving the burden on the server. By doing so, the server's response to program load requests will be far faster than if the files were stored on a hard disk.

Flash memory combines the advantages of an EPROM's low cost with an EEPROM's ease of reprogramming. These advantages will allow flash memory to make significant contributions to personal computers. Portable computers will be the first to benefit from this new technology, as flash-based disks increase their speed, operating time, and ruggedness. ■

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